Paleontological Research, vol. 4, no. 1, pp. 57-67, April 28, 2000


# Early Carboniferous miospores from the southern Kitakami Mountains, northeast Japan

**WEI-PING YANG**[1] **and JUN-ICHI TAZAWA**[2]

[1]*JSPS Fellow in the Department of Geology, Faculty of Science, Niigata University, 8050 Igarashi-ninocho, Niigata, 950-2181, Japan; Nanjing Institute of Geology and Palaeontology, Academia Sinica, Nanjing, 210008, P. R. China*

[2]*Department of Geology, Faculty of Science, Niigata University, 8050 Igarashi-ninocho, Niigata, 950-2181, Japan*

Received 7 July, 1999; Revised manuscript accepted 17 December, 1999

**Abstract. The first authenticated Early Carboniferous miospores in Japan are described from the upper part of the lower Hikoroichi Formation (HK2 Member) in the Hikoroichi area, southern Kitakami Mountains, northeast Japan. The stratigraphically significant miospores are *Auroraspora* sp. cf. *A. macra, Crassispora trychera, Schopfites* sp., *Spelaeotriletes crustatus*, and *S.* sp. cf. *S. pretiosus*, which suggest a late Tournaisian to early Viséan age and the "*Vallatisporites* Microflora" provincialism.**

**Key words: Hikoroichi Formation, late Tournaisian to early Viséan, miospores, southern Kitakami Mountains**

## Introduction

Because of their poor preservation and scarcity late Paleozoic plant fossils in Japan have aroused little interest among Japanese paleontologists. Microfloral research in the Upper Paleozoic of Japan is even more limited as it was commonly believed that spores and pollen are only preserved in terrestrial environments. However, there are many cases from around the world of Upper Paleozoic terrestrial microflora preserved in marine sediments, where they are significant to both stratigraphy and phytogeography (Sullivan, 1965; Yang, 1999). Prior to this paper there have been no reports of late Paleozoic miospores from Japan, although Takahashi and Yao (1969) reported the occurrence of problematic Permian plant microfossils from a sandstone block of the Jurassic melange in the Harayama area, Mino Belt, southwest Japan.

The Hikoroichi Formation is a Lower Carboniferous (Tournaisian and Viséan) formation, distributed in the Hikoroichi area, western part of the southern Kitakami Mountains (Figure 1). The Hikoroichi Formation overlies, with angular unconformity, the Middle Devonian Nakazato Formation (Okubo, 1951; Minato *et al.*, 1979), and is in turn overlain conformably by the Lower Carboniferous (Upper Viséan) Onimaru Formation (Mori and Tazawa, 1980; Tazawa, 1981, 1984b; Kawamura, 1983). According to Tazawa (1984b), the Hikoroichi Formation consists mostly of sandstone, with a basal conglomerate and intercalations of shales, acidic to intermediate tuffs and limestones, 560 m in total thickness, and is subdivided into the following four members in ascending order: (1) HK1 Member, sandstone dominant, 164 m thick, (2) HK2 Member, shale dominant, 102 m thick, (3) HK3 Member, basic to intermediate tuff dominant, 114 m thick, (4) HK4 Member, sandstone dominant, 180 m thick (Figure 2).

The miospores, described below, are from samples collected from the middle horizon of the HK2 Member at the Onimaru Quarry in the Hikoroichi area (Figures 1, 2). All the specimens are housed in the Department of Geology, Faculty of Science, Niigata University with the registered number (NU-P1-NU-P5). The other fossils, corals (Kato *et al.*, 1989), bryozoans (Sakagami, 1989), brachiopods (Tazawa, 1984a, 1985, 1989), gastropods (Kase, 1988), cephalopods (Niko, 1990) and trilobites (Kaneko, 1989) were collected from almost the same horizon in the same quarry. However, the plants alone were collected from the lowermost part of the HK3 Member in the same locality (Asama *et al.*, 1985, 1989). These fossils from the HK2 and HK3 Members of the Hikoroichi Formation in the Onimaru Quarry are summarized in Table 1.

## Miospore preservation and processing technique

The extraction of palynomorphs from Japanese Paleozoic rocks is difficult. Lithologies suitable for the preservation of palynomorphs make up only about 10% of the Hikoroichi Formation (see Figure 2). Further, the miospores preserved in the shales of the Hikoroichi Formation are rather dark and thermally mature and need strong oxidation after conventional palynological processing (Wood *et al.*, 1996). Processing of samples from the Hikoroichi Formation involved crushing the samples to pea size or even finer and

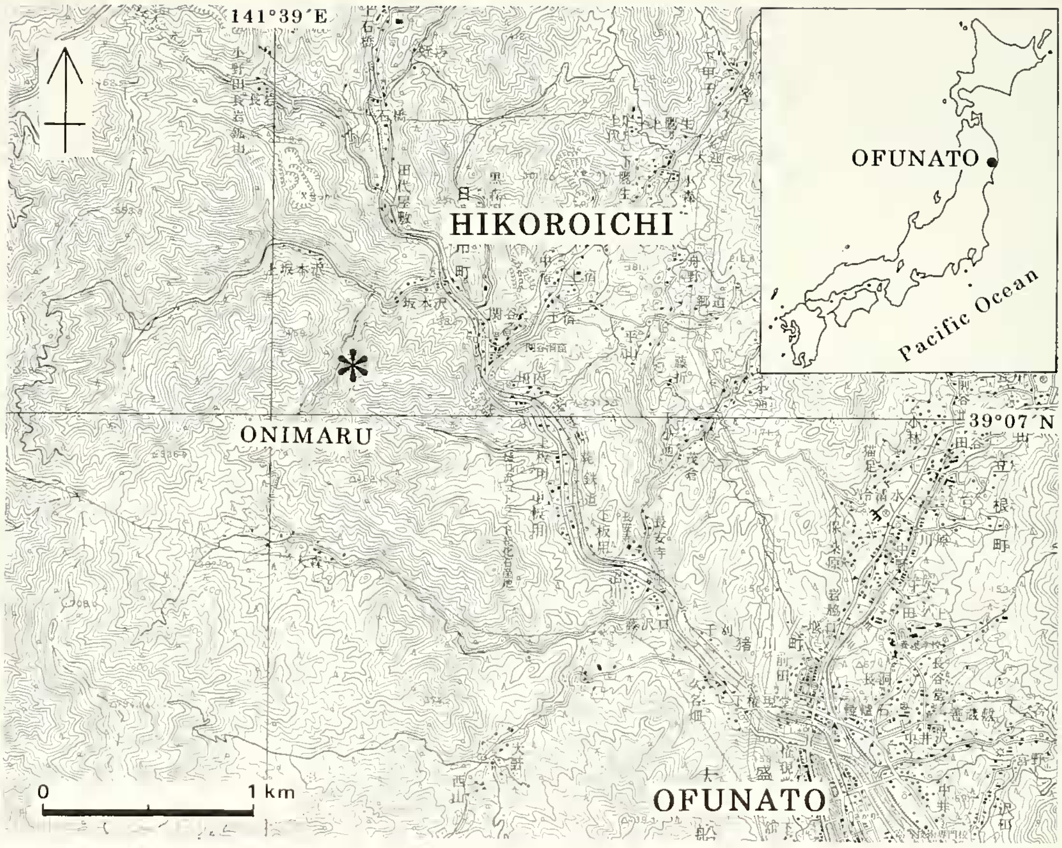


**Figure 1.** Index map showing the fossil locality (using the topographical map of "Sakari" scale 1:25,000 published by the Geographical Survey of Japan).

then demineralisation in dilute 35% HCL and 40% HF. Standard oxidation reagents did not react at all with the carbonized organic residues from the Hikoroichi Formation samples and so a very strong oxidation agent–fuming $HNO_3$ plus KCL ("fuming Schulze's solution") was used. The times required for oxidation using "fuming Schulze's solution" vary from sample to sample (as in Western Yunnan, Yang, 1993). In general, suitable oxidation will be achieved after seconds of oxidation. However, oxidation times for the Hikoroichi samples varied from one to several minutes even when heating the oxidation tube in a beaker of boiling water. Using this technique brown or light-brown coloured miospores were produced. Permanent slides were made with the rapid mounting medium Entellan.

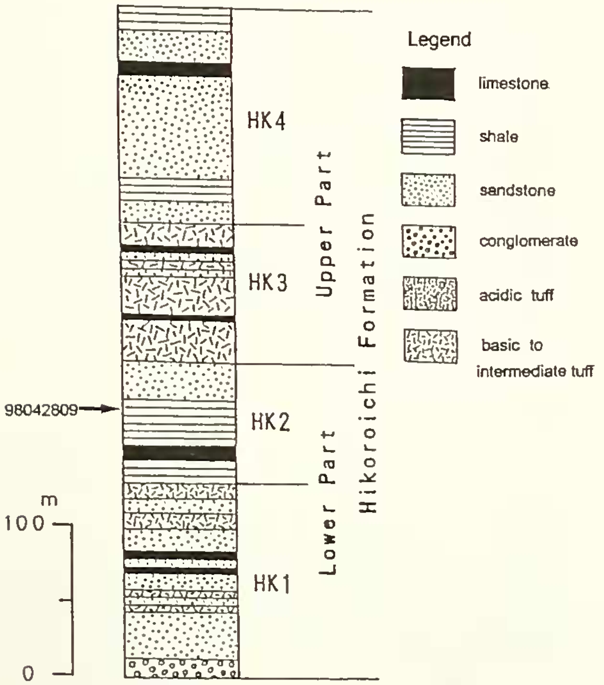


**Figure 2.** Columnar section of the Hikoroichi Formation in the Hikoroichi area; arrow showing the stratigraphical horizon of the miospore fossils collected (adopted from Tazawa, 1984b).

**Table 1.** The paleontological data from the HK2 and HK3 Members of the Hikoroichi Formation in the Onimaru Quarry, Hikoroichi area, southern Kitakami Mountains, northeast Japan

| Taxonomic group | Literature source | Species |
|---|---|---|
| **Lowermost part of the HK3 Member of the Hikoroichi Formation** | | |
| Plant | Asama *et al.* (1989) | *Psedusporochnus* n. sp., *Rhodeopteridium* sp. ?, *Sublepidodendron*? *wusihense*, *Lepidodendron* sp., *Archaeocalamites scrobiculatus* |
| **HK2 Member of the Hikoroichi Formation** | | |
| Coral | Kato *et al.* (1989) | *Amygdalophyllum* sp., *Bifossularia* sp., *Lophophyllidium* sp., *Multithecopora* sp., *Syringopora* sp. |
| Bryozoa | Sakagami (1989) | *Acanthocladia*? sp. cf. *A. pecularis*, *Hemitrypa*? sp. |
| Cephalopoda | Niko (1990) | *Adnatoceras onimarensis*, *Dolorthoceras* (?) sp., *Mooreoceras kinnoi, Neocycloceras* (?) sp., *Sueroceras nishimurai.* |
| Trilobite | Kaneko (1989) | *Linguaphillipsia choanjiensis*, *L. subconica*, *Liobole* (?) sp. |
| Gastropoda | Kase (1988) | *Baylea yvanii*, *Kawanamia onimarensis*, *Littorinides* sp., *Pseudozygopleura* (*Stephanozyga*) *nishimurai*, *Straparollus* (*Euomphalus*) *asanoi*, *S.* (*E.*) sp. |
| Brachiopoda | Tazawa (1989) | *Buxtonia* sp., *Lamellosathyris lamellosa*, *Linoprotonia* sp., *Marginatia* sp., *Unispirifer* sp. |
| Miospores | This paper | *Auroraspora* sp. cf. *A. macra*, *Calamospora* sp., *Crassispora trychera*, *Cyclogranisporites* sp., *Densosporites* sp., *Grandispora* sp. cf. *G. echinata*, *Leiotriletes* sp. cf. *L. incomptus*, *Microreticulatisporites araneum*, *Punctatisporites irrasus*, *P. minus*, *P. planus*, *Spelaeotriletes* sp. cf. *S. pretiosus*, *S. crustatus*, *Schophites* sp., *Verrucosisporites* sp. |

## Palynostratigraphy

The miospore assemblages from the upper part of the lower Hikoroichi Formation (HK2 Member) in the Onimaru Quarry are relatively abundant compared with the Middle Permian ones from the Kanokura Formation in the Kamiyasse area, southern Kitakami Mountains, northeast Japan (Yang and Tazawa, 2000). Stratigraphically significant species include *Auroraspora* sp. cf. *A. macra, Crassispora trychera, Schopfites* sp., *Spelaeotriletes crustatus* and *S.* sp. cf. *S. pretiosus*. Common species are *Auroraspora* sp., *Calamospora* sp., *Crassispora* sp., *Cyclogranisporites* sp., *Densosporites* sp., *Grandispora* sp. cf. *G. echinata, Leiotriletes* sp. cf. *L. incomptus*, *Microreticulatisporites araneum*, *Punctatisporites minus*, *P. irrasus*, *P. planus* and *Verrucosisporites* sp.

*Auroraspora macra* is a common species in Lower Carboniferous (mainly Tournaisian) assemblages around the world (Van der Zwan and Walton, 1981). This species ranges from the latest Devonian (Famennian) to the earliest Viséan in Western Europe (Clayton *et al.*, 1977) and Australia (Playford, 1990). In Canada it ranges from the Tournaisian to early Viséan (Utting, 1987a, b). *Spelaeotriletes pretiosus* is mainly distributed from the Tournaisian to early Viséan in Poland (Turnau, 1978, 1979). Since it first appears in the late Tournaisian strata in Ireland, it was selected as an index fossil for the PC (*Spelaeotriletes pretiosus-Raistrickia clavata*) Biozone by Higgs *et al.* (1988). However, it has occasionally been reported from the latest Devonian in Morocco (Rahmanin-Antari, 1990) and Eastern Alaska (Scott and Doher, 1967). *Spelaeotriletes crustatus* is commonly distributed from the late Famennian to late Tournaisian in SE Ireland (Higgs, 1975). *Crassispora trychera* is a characteristic species of the late Tournaisian to early Viséan in Western Europe (Clayton *et al.*, 1977), Poland (Turnau, 1978) and Canada (Utting, 1980; Utting *et al.*, 1989). It was once reported by Utting (1991) from the Lower Namurian in northern Yukon. *Schopfites* sp. is usually one of the common elements of the late Tournaisian and possible the early Viséan strata (Higgs *et al.*, 1988). The other species recorded include *Grandispora* sp. cf. *G. echinata, Leiotriletes* sp. cf. *L. incomptus, Densosporites* sp. and *Verrucosisporites* sp., which are also common members of the Early Carboniferous (mainly Tournaisian and Viséan) miospore assemblages from around the world.

Early Carboniferous (Tournaisian) miospore assemblages from Gengma, West Yunnan, China are correlated with the Western European BP and PC Biozones based on the occurrence of *Auroraspora macra*, *Kraeuselisporites hibernicus*, *Rugospora polyptycha*, *Spelaeotriletes balteatus* and *S. pretiosus* in the Longba Formation (Yang *et al.*, 1997).

All of the miospore taxa recorded from the Onimaru

| | | Western Europe<br>Higgs *et al.* (1988) | Lower Yangtze<br>Gao (1991) | S. Kitakami, Japan<br>This paper | Nova Scotia<br>Utting *et al.* (1989) |
|---|---|---|---|---|---|
| Carboniferous | Viséan | Pu: *Lycospora pusilla* | Pu: *L. pusilla* | ? | No palynomorphs |
| Carboniferous | Tn3 | *Schopfites claviger*<br>CM: *Auroraspora macra* | *S. claviger*<br>CM: *A. macra* | *Schopfites* sp.<br>*Crassispora trychera*<br>*Auroraspora macra*<br>*Spelaeotriletes pretiosus* | *C. decorus - S. claviger*<br>*S.pretiosus* var.*pretiosus* |
| Carboniferous | Tn3 / Tn2 | PC: *Spelaeotriletes pretiosus*<br>*Schopfites claviger* | PB: *S.pretiosus*<br>*Cingulizonates bialatus* | | *V. vallatus* |
| Carboniferous | Tn2 | BP *Spelaeotriletes balteatus*<br>*Rugospora polyptycha* | ? | | Section faulted<br>possibly incomplete |
| Carboniferous | Tn2 | HD: *Kraeuselisporites hibernicus*<br>*Umbonatisporites distinctus* | ? | | *E. rotatus*<br>*H. explanatus* |
| Carboniferous | Tn1 | VI: *Vallatisporites verrucosus*<br>*Retusotriletes incohatus* | VI: *V. verrucosus*<br>*R. incohatus* | | not studied |
| Devonian | Tn1 | LN: *Retispora lepidophyta*<br>*Verrucosisporites nitidus* | LN: *R. lepidophyta*<br>*V. nitidus* | | unconformity |

**Figure 3.** Suggested correlation of miospore assemblages from the southern Kitakami Mountains with late Devonian to early Carboniferous miospore biozones of Western Europe, Lower Yangtze and Nova Scotia.

Quarry are typical members of the latest Tournaisian (Tn3) in Western Europe (PB and CM Biozones), China (PC and CM equivalent Biozones), Nova Scotia and eastern Canada (*Spelaeotriletes pretiosus* var. *pretiosus* Biozone and *Crassispora trychera-Colatisporites decorus* Biozone). But most of them can extend to the early Viséan. A correlation chart of these biozones is provided in Figure 3.

The brachiopods (Tazawa, 1984a, 1985, 1989), gastropods (Kase, 1988) and cephalopods (Niko, 1990) from the HK2 Member of the Hikoroichi Formation at the Onimaru Quarry indicate an early Viséan age (see Table 1). However, the palynomorph assemblages from that member have a strong late Tournaisian character and are without the typical Viséan genus *Lycospora*. Furthermore, some plant fossils (*Archaeocalamites scrobiculatus, Knorria* sp. and *Sublepidodendron*? *wushiense*) were described by Asama *et al.* (1985, 1989) from the lowermost part of the H3 Member of Kawamura (1983), which is supposed to be equal to the HK3 Member of Tazawa (1985) at the same locality (see Table 1). *Archaeocalamites scrobiculatus* is one of the dominant representatives of Viséan plant assemblages in both South China and North China (Wu, 1995), and has also been reported by Wu (1995) from the Tournaisian of South China together with *Eolepidodendron wusihense* Sze or *Sublepidodendron*? *wusihense* Sze. It seems likely that the plant-bearing bed of the lowermost part of the HK3 Member is early Viséan. The Viséan *Lycospora pusilla* Biozone can be informally divided into a lower division containing rare *Lycospora pusilla* and an upper division with abundant representatives of that species (Higgs, 1996). This suggests that the miospore-containing strata of Onimaru Quarry can be dated as late Tournaisian to early Viséan rather than solely early Viséan as suggested by the brachiopods, gastropods and cephalopods.

Sullivan (1965, 1967) first defined the differences between the various Early Carboniferous microfloral assemblages around the world and demonstrated a clear relationship between their distribution and their probable paleolatitude. He described five distinct assemblage suites in the Early Carboniferous, two (*Vallatisporites* Suite and *Lophozonotriletes* Suite) in the Tournaisian and three (*Grandispora* Suite, *Monilospora* Suite and Kazakhstan Suite) in the Upper Mississippian (late Viséan-early Namurian). In 1981, Van der Zwan supported Sullivan's conclusion through his statistically based correlation of late Tournaisian and early Viséan assemblages from 14 selected areas using both Jaccard and Simpson correlation coefficients. Clayton (1985) made some progress on microflora provinces proposing seven microfloras instead of Sullivan's five suites. In general, five microfloras can be distinguished in the Early Carboniferous (Clayton, 1985, figs. 2, 3) around the world: the *Granulatisporites frustulentus* Microflora in Australia, the *Spelaeotriletes balteatus* Microflora in North Africa, the Kazakhstan Microflora in Kazakhstan, and the *Vallatisporites* Microflora (middle Tournaisian to early Viséan) and the *Grandispora* Microflora (middle-late Viséan), which extended from the eastern United States and eastern Canada through Western Europe to China. The *Lophozonotriletes* Microflora (middle Tournaisian to early Viséan) and the *Monilospora* Microflora (middle-late Viséan) were mainly distributed in Western Canada, Spitsbergen and the northwestern part of Russia. Assemblages from Eastern Europe are more or less transitional in nature between the *Vallatisporites* Microflora and the *Lophozonotriletes* Microflora.

The microflora in the southern Kitakami Mountains can be circumscribed within the *Vallatisporites* Microflora in the sense of Clayton's division (Clayton, 1985) based on the presence of *Auroraspora* sp. cf. *A. macra*, *Crassispora trychera*, *Spelaeotriletes crustatus*, *S.* sp. cf. *S. pretiosus* and *Schopfites* sp.

## Systematic palynology

The suprageneric classification used is mainly based upon the schemes by Potonié and Kremp (1954), Potonié (1956, 1975), Dettmann (1963) and Smith and Butterworth (1967).

Anteturma Sporites H. Potonié, 1893
Turma Triletes Reinsch emend. Dettmann, 1963
Suprasubturma Acavatitriletes Dettmann, 1963
Subturma Azonotriletes Luber emend. Dettmann, 1963
Infraturma Laevigati (Bennie and Kidston) R. Potonié, 1956
Genus ***Leiotriletes*** (Naumova) Potonié and Kremp, 1954

*Type species.*—*Leiotriletes sphaerotriangulus* (Loose) Potonié and Kremp, 1954.

***Leiotriletes*** sp. cf. ***L. incomptus*** (Felix and Burbridge) Higgs, Clayton and Keegan, 1988

Figure 4.9

*Compare.*—

*Punctatisporites incomptus* Felix and Burbridge, 1967, p. 357, pl. 53, fig. 12.

*Leiotriletes incomptus* (Felix and Burbridge). Higgs *et al.*, 1988, p. 50, pl. 1, fig. 9.

*Material.*—Seven specimens logged from NU-P1 to NU-P4, Figure 4.9 from NU-P2.

*Description.* — Trilete acamerate miospores. Amb rounded triangular, sides convex. Suturae simple and distinct, extending approximately to the equator. Laesurae bordered by flexuous labra. Exine laevigate, approximately 1.5-2 μm thick.

*Diameter.*—38-45 μm.

*Remarks.*—The Kitakami specimens are similar to those recorded by Felix and Burbridge (1967) as *Punctatisporites incomptus* and Higgs *et al.* (1988) as *Leiotriletes incomptus*, but are significantly smaller than the type (60-90 μm) and lack the prominent labra.

Genus ***Punctatisporites*** Ibrahim emend. Potonié and Kremp, 1954

*Type species.* — *Punctatisporites punctatus* (Ibrahim) Ibrahim, 1933.

***Punctatisporites irrasus*** Hacquebard, 1957

Figure 4.7

*Punctatisporites irrasus* Hacquebard, 1957, p. 308, pl. 1, figs. 7, 8; Sullivan, 1964, p. 372, pl. 2, figs. 3.4; Higgs *et al.* 1988, p. 51, pl. 1, fig. 17.

*Punctatisporites* cf. *irrasus* Hacquebard. Dolby and Neves, 1970, p. 365, pl. 1, fig. 1.

*Material.*—Six specimens logged from NU-P2 to NU-P5, Figure 4.7 from NU-P2.

*Description.*—Acamerate trilete miospores. Amb subcircular. Suturae distinct to obscure with a narrow labra. Suturae extend 1/2 to 3/4 of the spore radius, usually darkening along its length. Exine 1-2 μm thick, often laevigate or finely infragranulate accompanying large compression folds.

*Diameter.*—45-54 μm.

*Remarks.*—The Kitakami specimens conform very closely to those described by Sullivan (1964), Dolby and Neves (1970), and Higgs *et al.* (1988), who reported size ranges of 59-98 μm, 42-65 μm and 50-92 μm, respectively.

Infraturma Apiculati Bennie and Kidston emend. R. Potonié, 1956
Genus ***Schopfites*** Kosanke, 1950

*Type species.*—*Schopfites dimorphus* Kosanke, 1950.

***Schopfites*** sp.

Figure 4.12

*Material.*—One specimen logged from NU-P4, distal view.

*Description.*—Miospore trilete, acamerate. Amb oval to circular. Suturae distinct to indistinct, straight, extend almost to equator of miospores. Intexine thin, indistinct to distinct, approximately conformable with the amb, about 3/4 of the diameter. Distal surface and equator ornamented with pilae, rounded baculae, and rare verrucae. The size of the elements ranges from 0.5-3 μm in height and 0.5-2.5 μm in width. Sculptural elements are normally discrete and closely spaced. Proximal surface laevigate.

*Diameter.*—35 μm.

*Remarks.* — This specimen is attributed to the genus *Schopfites* on the basis of the type and distribution of the ornamentation, patchy distal ornament predominantly of verrucae, bacula or pila suggested by Higgs *et al.* (1988).

Genus ***Verrucosisporites*** Ibrahim emend. Smith, 1971

*Type species.* — *Verrucosisporites verrucosus* (Ibrahim) Ibrahim, 1933.

***Verrucosisporites*** sp.

Figure 4.8

*Material.*—One specimen from NU-P2.

*Description.*—Trilete acamerate miospore. Amb rounded triangular. Suturae distinct, simple, length 2/3 to 3/4 the spore radius. Exine 2-3 μm thick. Distal surface and equatorial region of proximal surface ornamented with verrucae. Verrucae 1.5-2.5 μm in basal diameter, 1.5-2 μm in height with predominantly rounded tops. Elements evenly spaced 3-5 μm apart.

*Diameter.*—40 μm.

*Remarks.* — This sole specimen from the southern Kitakami Mountains is unlike the previously described species of the genus *Verrucosisporites*.

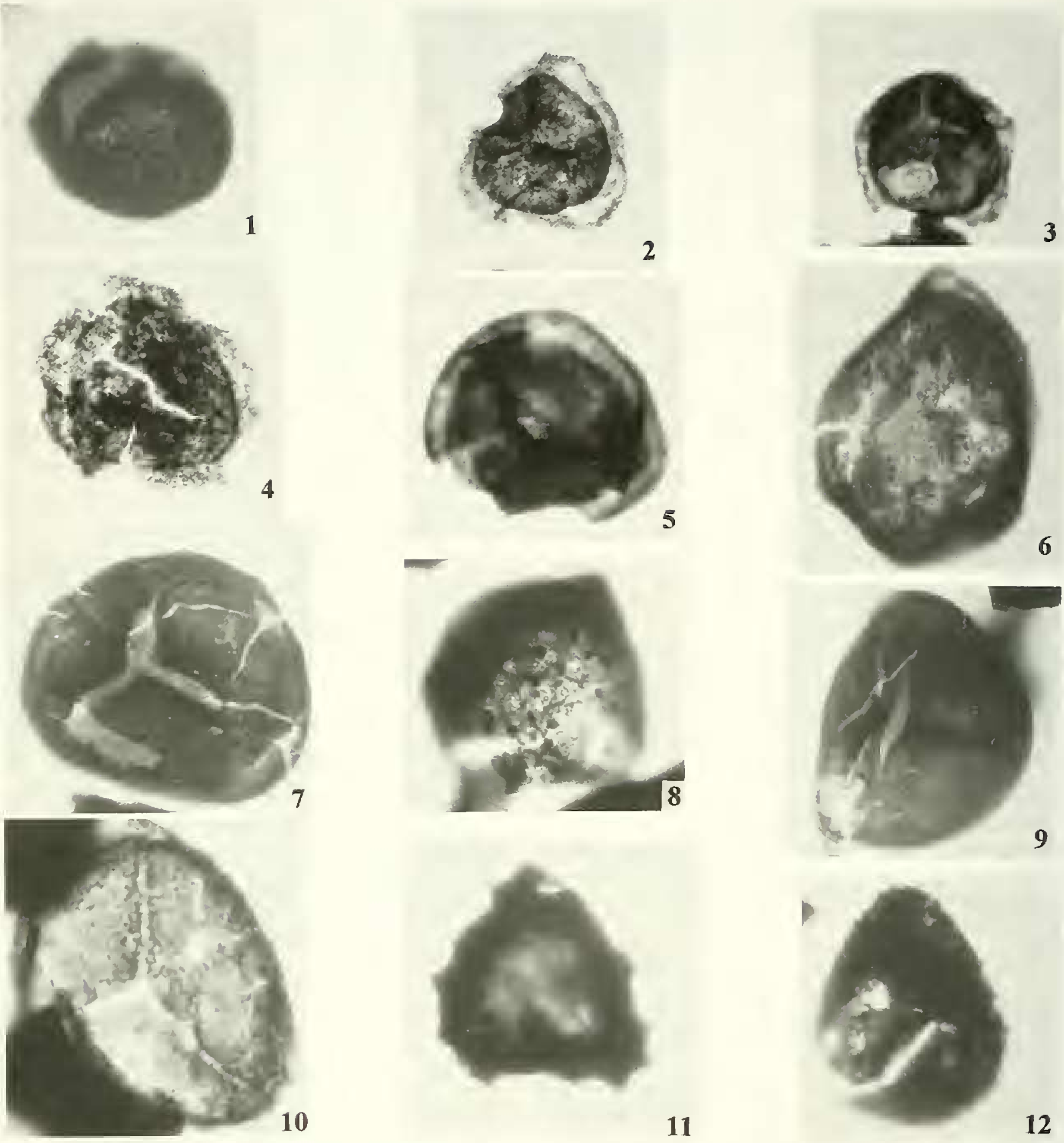

**Figure 4.** Early Carboniferous (late Tournaisian to early Viséan) miospores from the HK2 Member of the Hikoroichi Formation in the Onimaru Quarry, southern Kitakami Mountains, northeast Japan. The miospores are illustrated at the magnification of ×700. **1**. *Microreticulatisporites araneum* Higgs, Clayton and Keegan, proximal view, high focus, NU-P5. **2, 3**. *Auroraspora* sp. cf. *A. macra* Sullivan. **2**. Proximal view, median focus, NU-P4. **3**. Proximal view, high focus, NU-P3. **4**. *Spelaeotriletes* sp. cf. *S. pretiosus* (Playford) Neves and Belt, proximal view, median focus, NU-P4. **5, 6**. *Spelaeotriletes crustatus* Higgs. **5**. Proximal view, high focus, NU-P5. **6**. Proximal view, median focus, NU-P3. **7**. *Punctatisporites irrasus* Hacquebard, proximal view, high focus, NU-P2. **8**. *Verrucosisporites* sp., distal view, median focus, NU-P2. **9**. *Leiotriletes* sp. cf. *L. incomptus* (Felix and Burbridge) Higgs, Clayton and Keegan, proximal view, median focus, NU-P2. **10**. *Crassispora trychera* Neves and Ioannides, proximal view, high focus, NU-P2. **11**. *Densosporites* sp., distal view, median focus, NU-P2. **12**. *Schopfites* sp., proximal view, median focus, NU-P4.

Infraturma Murornati Potonié and Kremp, 1954
Genus ***Microreticulatisporites*** Knox emend. Potonié and Kremp, 1954

*Type species.—Microreticulatisporites lacunosus* (Ibrahim) Knox, 1950.

***Microreticulatisporites araneum*** Higgs, Clayton and Keegan, 1988

Figure 4.1

*Dictyotriletes* sp. Keegan, 1977, p. 552, pl. 2, figs. 13-14.
*Dictyotriletes* sp. B, Playford, 1978, p. 128, pl. 8, figs. 8-10.
*Microreticulatisporites araneum* Higgs, Clayton and Keegan, 1988, p. 65, pl. 7, figs. 6, 9-10.

*Material.*—Six specimens logged from NU-P2, NU-P3, NU-P5, Figure 4.1 from NU-P5.

*Description.*—Trilete acamerate miospores. Amb subcircular to convexly triangular. Suturae distinct to indistinct, straight to slightly sinuous and extending to the spore margin. Exine 1.5-2μm thick, ornamented with close reticulum of tiny muri. Muri 0.5-1μm in thickness, enclosing lumina 2-3 μm in width. Luminar usually polygonal to subcircular in shape. Reticulation normally comprehensive but occasionally less evident near equator and on the proximal surface.

*Diameter.*—30-35 μm.

*Remarks.*—These specimens, recorded from the southern Kitakami Mountains, are definitely attributed into *M. araneum* because of their particular reticulation and the size range.

Suprasubturma Laminatitriletes Smith and Butterworth, 1967
Subturma Zonolaminatitriletes Smith and Butterworth, 1967
Infraturma Crassiti
Genus ***Crassispora*** Bharadwaj emend. Sullivan, 1964

*Type species.—Crassispora kosankei* Potonié and Kremp emend. Bharadwaj, 1957.

***Crassispora trychera*** Neves and Ioannides, 1974

Figure 4.10

*Crassispora trychera* Neves and Ioannides, 1974, p. 78, pl. 7, figs. 6-8; Higgs *et al.*, 1988, p. 55, pl. 3, fig. 24.

*Material.*—Four specimens logged from NU-P2 and NU-P3, Figure 4.10 from NU-P2.

*Description.*—Miospores trilete, variably camerate. Amb subcircular to rounded triangular. Suturae straight, simple, extend almost to the margin of spores. The subparallel peripheral folding is often seen around the equator surface. Distal surface ornamented by the combination of coni, pila and grana (up to 1-1.5 μm in height).

*Diameter.*—53-68 μm.

*Remarks.*—These specimens are attributed to *C. trychera* by the presence of variable camerate and distal ornament of coni, pila and grana.

Suprasubturma Psedodsaccititriletes Richardson, 1965
Infraturma Monopseudosacciti Smith and Butterworth, 1967
Genus ***Auroraspora*** Hoffmeister, Staplin and Malloy emend. Richardson, 1960

*Type species.—Auroraspora solisortus* Hoffmeister, Staplin and Malloy, 1955.

***Auroraspora*** sp. cf. ***A. macra*** Sullivan, 1968

Figure 4.2, 4.3

*Compare.*—
*Auroraspora macra* Sullivan, 1968, p. 124, pl. 27, figs. 6-10; Higgs *et al.*, 1988, p. 69, pl. 9, figs. 17-19.

*Material.*—Ten specimens logged from NU-P1 to NU-P4, Figure 4.2 from NU-P4 and Figure 4.3 from NU-P3.

*Diagnosis.*—Size 48-68 μm, mean 58 μm (65 specimens); amb subcircular to irregular; exoexine laevigate, intexine laevigate to scabrate; trilete mark exceeds two-thirds radius of spore body

*Description.*—Trilete camerate miospores. Amb frequently irregular due to folding. Trilete straight, simple. Suturae distinct with labra extend up to 2/3 or more of the spore radius. Exoexine thin, thickness not determinable, often finely folded in an irregular pattern, usually pitted and torn with fine grana. The equatorial darkened zone described by Higgs *et al.* (1988) is occasionally observed, Intexine 1.5 μm thick.

*Diameter.*—30-35 μm.

*Remarks.*—The specimens from the Hikoroichi Formation are similar to those described by Sullivan (1968) and Higgs *et al.* (1988) but are significantly smaller. Higgs *et al.* (1988) extend the size range of *A. macra* to 35-65 μm. The present specimens fall beyond this range and so are not attributed to *A. macra sensu stricto.*

Genus ***Spelaeotriletes*** Neves and Owens, 1966

*Type species.—Spelaeotriletes triangulus* Neves and Owens, 1966.

***Spelaeotriletes crustatus*** Higgs, 1975

Figure 4.5, 4.6

*Spelaeotriletes crustatus* Higgs, 1975, pl. 6, figs. 7-9; non pl. 6, figs. 4-6.
*Spelaeotriletes exiguus* Keegan, 1977, p. 556, pl. 4, figs. 7-10.
*Spelaeotriletes resolutus* Higgs. Van der Zwan and Van Veen, 1978, pl. 2, fig. 1; Van der Zwan, 1980, pl. 18, fig. 5; Higgs *et al.*, 1988, pl. 13, figs. 8-9.

*Material.*—Seven specimens logged from NU-P3 to NU-P5, Figure 4.5 from NU-P5 and Figure 4.6 from NU-P3.

*Description.*—Trilete camerate miospores. Amb convexly triangular with rounded apices. Suturae distinct, straight to slightly sinuous. Suturae extend up to 3/4 of the spore radius, terminating in curvaturae perfectae. Exoexine 1-2 μm in thickness, distal surface and equator densely ornamented with fine to coarse grana and less commonly coni and small spinae. Sculptural elements 1–1.5 μm in width, up to 1 μm in height, discrete but often fused to give short irregular-shaped rugulae. Intexine distinct to obscure, laevigate, almost conformable with amb, comprising 3/4 or more of the total spore diameter and attached to the exoexine on the proximal surface only.

*Diameter.*—50–60 μm.

*Remarks.*—These specimens recorded from the southern Kitakami Mountains are similar to *S. crustatus* with ornament mainly of fine to coarse grana instead of coni or small spinaes usually distributed on the distal surface and equator.

### ***Spelaeotriletes*** sp. cf. ***S. pretiosus*** (Playford) Neves and Belt, 1971

Figure 4.4

*Compare.*—

*Pustulatisporites pretiosus* Playford, 1964, p. 19, pl. 4, figs. 9–7; pl. 5, fig. 1; text-fig.1a.

*Spelaeotriletes pretiosus* (Playford). Neves and Belt, 1971, p. 1241; Higgs et al., 1988, pl. 13, figs. 16–18.

*Material.*—Six specimens logged from NU–P2,NU–P4, Figure 4.4 from NU–P4.

*Description.*—Trilete camerate miospores. Amb rounded to convexly triangular. Trilete distinct to indistinct, sinuous, suturae extend almost to the equator, terminating in curvaturae imperfectae. Exine infragranulate, 2 μm thick at the equator. Exoexine ornamented with low, simple verrucae, mammillate verrucae and wide-based spinae. Ornament evenly to irregular distributed, usually concentrated at the distal polar region and often discernible at the equator. Verrucae subcircular in basal outline, 2–3 μm in width, 1–2 μm in height, with rounded flattened or more commonly mammillate tops. Bases of verrucae discrete, or fused to form very large irregular-shaped verrucae.

*Diameter.*—35–38 μm.

*Remarks.*—The present specimens are assigned to *Spelaeotriletes* cf. *pretiosus* on the basis of the type of ornament. Playford (1964) indicated a size of 98 to 195 μm for the type material of *S. pretiosus*. Higgs *et al.* (1988) recorded specimens between 68 and 110 μm. The present specimens are considerably smaller.

Infraturma Cingulicamerati Neves and Owens, 1966
Genus ***Densosporites*** Berry emend. Butterworth, Jansonius, Smith and Staplin, 1964

*Type species.*—*Densosporites convensis* Berry in Butterworth, Jansonius, Smith and Staplin, 1963.

### ***Densosporites*** sp.

Figure 4.11

*Densosporites* sp. A, Higgs, Clayton and Keegan, 1988, p.79, pl. 15, figs 10, 11.

*Material.*—Seven specimens logged from NU–P1 to NU–P4, Figure 4.11 from NU–P2.

*Description.*—Trilete cinguli-camerate miospores. Amb convexly triangular to subtriangular. Suturae obscure, simple, often gaping. Intexine often obscure. Exine 1–1.5 μm thick. Equatorial margin and distal surface ornamented with wide-based spinae, 1.5-2.5 μm in basal diameter and 1.5–3 μm in height. Spinae discrete but more commonly fused at their bases to form low sinuous and irregular cristae.

*Diameter.*—33–45 μm.

*Remarks.*—The Kitakami specimens are similar to those described by Higgs *et al.* (1988) in Ireland but just slightly smaller in size and with more dense ornament on the distal surface.

## Conclusion

1. These records represent the first authenticated occurrence of Early Carboniferous miospores in Japan.

2. This significant miospore data might extend the geological age of the HK2 Member of the Hikoroichi Formation into late Tournaisian to early Viséan.

3. This miospore assemblage from the Hikoroichi area is more likely included in the *Vallatisporites* Microflora, which is to some degree similar to the Euramerican Realm in terms of megafloral phytogeography.

## Acknowledgments

The first author (YWP) is indebted to JSPS for support in Japan. This research was financially assisted by Monbusho. We sincerely thank Professors Y. Hasegawa and A. Matsuoka of Niigata University for use of their laboratory and technical support. Appreciation also extended to Professor T. Kimura of the Institute of Natural History, Tokyo for information about the Late Paleozoic plants in Japan. Thanks must also go to three reviewers, Professor G. Playford, and Drs. J. Utting and D. Mclean for their careful comments and suggestions, from which this paper greatly benefited.

## References

Asama, K., Asano, T., Sato, E. and Yamada, Y., 1985: Early Carboniferous plants from the Hikoroichi Formation, southern Kitakami Massif, northeast Japan (preliminary report). *The Journal of the Geological Society of Japan*, vol. 91, p. 425–426, pl. 1. (*in Japanese*)

Asama, K., Asano, K., Yamada, Y. and Sato, E., 1989: Pterophyta. *In*, Ofunato City Museum *ed.*, *Fossils of Onimaru*, p. 109–114, pls. 1–4, Kawashima Insatsu, Ichinoseki. (*in Japanese*)

Butterworth, M. A., Jansonius, J., Smith, A. H. V. and Staplin, F. L., 1963: *Densosporites* (Berry) Potonié and Kremp and related Genera. *5eme Congrès International de Stratigraphie et de Géologie du Carbonifère, Compte Rendu, Paris, 1963*, vol. 3, p. 1049–1058.

Clayton, G., 1985: Dinantian miospores and inter-continental correlation. *Dixième Congrès International de Stratigraphie et de Géologie du Carbonifère, Compte Rendu, Madrid, 1983*, vol. 4, p. 9–23.

Clayton, G., Coquel, R., Doubinger, J., Loboziak, S., Owens, B. and Streel, M., 1977: Carboniferous miospores of western Europe: illustration and zonation. *Mededelingen Rijks Geologische Dienst*, vol. 29, p. 1-72.

Dettmann, M. E., 1963: Upper Mesozoic microfloras from south-eastern Australia. *Proceedings of the Royal Society of Victoria*, vol. 77, p. 1-148, pls. 1-6.

Dolby, G. and Neves, R., 1970: Palynological evidence concerning the Devonian-Carboniferous boundary in the Mendips, England. *6ème Congrès Internationale de Stratigraphie et de Géologie du Carbonifère, Compte Rendu, Sheffield, 1967*, vol. 2, p. 631-646.

Felix, C. and Burbridge, P. P., 1967: Palynology of the Springer Formation of Southern Oklahoma, U.S.A. *Palaeontology*, vol. 10, p. 349-425, pls. 1-3.

Gao, L.D., 1991: The new development of palynostratigraphy of Late Devonian to Early Carboniferous in the Lower Valley area of Yangtze River. *Geology of China*, vol. 8, p. 28-30. (*in Chinese*)

Hacquebard, P.A., 1957: Plant spores in coal from the Horton Group (Mississippian) of Nova Scotia. *Micropaleontology*, vol. 3, p. 301-324, pl. 1.

Higgs, K., 1975: Upper Devonian and Lower Carboniferous miospore assemblages from Hook Head, County Wexford, Ireland. *Micropaleontology*, vol. 21, p. 393-419, pls. 1-3.

Higgs K.T., 1996: Taxonomy and systematic study of some Tournaisian (Hastarian) spores from Belgium. *Review of Palaeobotany and Palynology*, vol. 93, nos. 1-4, p. 269-297.

Higgs, K., Clayton, G. and Keegan, J. B., 1988: Stratigraphic and systematic palynology of the Tournaisian rocks of Ireland. *The Geological Survey of Ireland, Special Paper*, no. 7, p. 1-93, pls. 1-17.

Hoffmeister, W. S., Staplin, F. L. and Malloy, R. E., 1955: Mississippian plant spores from the Hardinsburg Formation of Illinois and Kentucky. *Journal of Paleontology*, vol. 29, p. 372-399, pls. 1-3.

Ibrahim, A.C., 1933: *Sporenformen des Aegirhorizonts des Ruhr-Reviers*. Triltsch Wurzburg, Berlin, 46 p.

Kaneko, A., 1989: Trilobite. *In*, Ofunato City Museum ed., *Fossils of Onimaru*, p. 87-102, pls. 1-3, Kawashima Insatsu, Ichinoseki. (*in Japanese*)

Kase, T., 1988: Early Carboniferous (Viséan) gastropods from the Hikoroichi Formation of the Kitakami Mountains, northeast Japan. *Transactions and Proceedings of* the *Palaeontological Society of Japan, New Series*, no. 149, p. 361-370.

Kato, M., Niikawa, I., Kawamura, T., Ezaki, Y. and Sato, E., 1989: Coral. *In*, Ofunato City Museum ed., *Fossils of Onimaru*, p. 13-24, pls. 1-6, Kawashima Insatsu, Ichinoseki. (*in Japanese*)

Kawamura, T., 1983: The Lower Carboniferous formations in the Hikoroichi region, southern Kitakami Mountains, northeast Japan (Part 1)—Stratigraphy of the Hikoroichi Formation. *The Journal of the Geological Society of Japan*, vol. 89, p. 707-722. (*in Japanese with English abstract*)

Keegan, J. B., 1977: Late Devonian and early Carboniferous miospores from the Galley Head-Leap Harbour region of southwest Ireland. *Pollen et Spores*, vol. 19, p. 545-573, pls. 1-4.

Knox, E. M., 1950: The spores of *Lycopodium*, *Phylloglossum*, *Selaginella* and *Isoetes* and their value in the study of microfossils of Palaeozoic age. *Transactions of the Botanical Society of Edinburgh*, vol. 35, p. 211-357.

Kosanke, R.M., 1950: Pennsylvanian spores of Illinois and their use in correlation. *Bulletin of Illinois Geological Survey*, vol. 74, p. 1-28.

Minato, M., Hunahashi, M., Watanabe, J. and Kato, M., 1979: *Variscan Geohistory of Northern Japan: The Abean Orogeny*. 427 p., Tokai University Press, Tokyo.

Mori, K. and Tazawa, J., 1980: Discovery and significance of Visèan rugose corals and brachiopods from the type locality of the Lower Carboniferous Hikoroichi Formation. *The Journal of the Geological Society of Japan*, vol. 86, p. 143-146. (*in Japanese*)

Neves, R. and Belt, E. S., 1971: Some observations on Namurian and Visèan spores from Nova Scotia, Britain and Northern Spain. *6ème Congrès Internationale de Streatigraphie et de Géologie du Carbonifère, Compte Rendu, Sheffield, 1967*, p. 1233-1247.

Neves, R., Gueinn, K. J., Clayton, G., Ioannides, N. S., Neville, R. S. W. and Kruszewska, K., 1973: Palynological correlations within the Lower Carboniferous of Scotland and Northern England. *Transactions of the Royal Society of Edinburgh*, vol. 69, p. 23-70, pls. 1-4.

Neves, R. and Ioannides, N., 1974: Palynology of the Spilmersford Borehole. *Bulletin of the Geological Survey of Great Britain*, vol. 12, p. 73-97.

Neves, R. and Owens, B., 1966: Some Namurian camerate miospores from the English Pennines. *Pollen et Spores*, vol. 8, p. 337-360.

Niko, S., 1990: Early Carboniferous (Visèan) cephalopods from the Hikoroichi Formation, southern Kitakami Mountains. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, no. 159, p. 554-561.

Okubo, M., 1951: Zur Hikoroichi-Serie und der bedentenden Diskordanz vor der Hikoroichi-Epoche. *The Journal of the Geological Society of Japan*, vol. 57, p.195-209. (*in Japanese with German abstract*)

Playford, G., 1964: Miospores from the Mississippian Horton Group, Eastern Canada. *Bulletin of Geological Survey of Canada*, vol. 107, p. 1-47, pls. 1-6.

Playford, G., 1978: Lower Carboniferous spores from the Ducabrook Formation, Drummond Basin, Queensland. *Palaeontographica*, B, vol. 167, p. 105-160.

Playford, G., 1990: Australian Lower Carboniferous miospores relevant to extra-Gondwanic correlations: an evaluation. *Courier Forschungsinstitut Senckenberg*, vol. 130, p. 85-125.

Potonié, H., 1893. Die Flora des Rotliegenden von Thuringen. *Kongelige Preussische Geologie*, vol. 9, p. 1-298.

Potonié, R., 1956: Synopsis der Gattungen der Sporae dispersae, Teil 1: Sporites. *Geologischen Jahrbuch*, vol. 23, p. 1-103.

Potonié, R., 1975: Beiträge zur Sporologie. *Fortschritte in der Geologie von Rheinland und Westfalen*, vol. 63, p. 1-281, pls. 1-18.

Potonié, R. and Kremp, G., 1954: Die Gattungen der paläozoischen Sporea dispersae und ihre Stratigraphie. *Geologisches Jahrbuch*, vol. 69, p. 111-194.

Rahmani-Antari, M., 1990: Étude palynologique et evaluation de l'indice de alternation thermique du Palezoique du forage DOT1 (bassin des Doukkala Centre-Ouest marocain). *Review of Paleobotany and Palynology*, vol. 66, p. 211-227, pls. 1-2.

Richardson, J. B., 1960: Spores from the Middle Old Red Sandstone of Cromarty, Scotland. *Palaeontology*, vol. 3, p. 45-63.

Richardson, J. B., 1965: Middle Old Red Sandstone spore assemblages from the Orcadian Basin, north-east Scotland. *Palaeontology*, vol. 7, p. 559-605.

Sakagami, S., 1989: Bryozoa. *In*, Ofunato City Museum *ed.*, *Fossils of Onimaru*, p. 37-44, pls. 1-3, Kawashima Insatsu, Ichinoseki. (*in Japanese*)

Scott, J. and Doher, K., 1967: Palynological evidence for Devonian age of the Nation River Formation, East-Central Alaska. *U.S. Geological Survey Professional Paper,* 575B, p. B45-B49, pl. 1.

Smith, A. H. V. and Butterworth, M. A., 1967: Miospores in coal seams of the Carboniferous of Great Britain. *Special Paper in Palaeontology*, no. 1, p. 1-324, pls. 1-27.

Smith, A. H. V., 1971. Genus *Verrucosisporites* Ibrahim emend. *C.I.M.P. Spores*, vol. 4, p. 35-87.

Sullivan, H. J., 1964: Miospores from the Drybrook Sandstone and associated measures in the Forest of Dean Basin, Gloucestershire. *Palaeontology*, vol. 7, p. 351-392, pls. 1-2.

Sullivan, H. J., 1965: Palynological evidence concerning the regional differentiation of Upper Mississippian floras. *Pollen et Spores*, vol. 7, p. 539-564.

Sullivan, H. J.,1967: Regional differences in Mississippian spore assemblages. *Review of Palaeobotany and Palynology*, vol. 1, p. 185-192.

Sullivan, H. J., 1968: A Tournaisian spore flora from the Cementstone Group of Ayrshire, Scotland. *Palaeontology*, vol. 11, p. 116-131, pls. 1-3.

Takahashi, K. and Yao, A., 1969: Plant microfossils from the Permian sandstone in the southern marginal area of the Tanba Belt. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, no. 73, p. 41-48, pls. 4-6.

Tazawa, J., 1981: Notes on some Carboniferous brachiopods from the Kitakami Mountains, northeast Japan. *Saito Ho-on Kai Museum Research Bulletin*, no. 49, p. 53-60, pl. 4.

Tazawa, J., 1984a: Occurrence of *Gigantoproductus* (Carboniferous Brachiopoda) from the lower Hikoroichi Formation, Kitakami Mountains and its significance. *Earth Science* (*Chikyu Kagaku*), vol. 38, p. 132-134, pl. 1. (*in Japanese*)

Tazawa, J., 1984b: Early Carboniferous (Viséan) brachiopods from the Hikoroichi Formation of the Kitakami Mounatains, northeast Japan. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, no. 133, p. 300-312, pl. 61.

Tazawa, J., 1985: Carboniferous brachiopods *Marginatia* and *Unispirifer* from the Hikoroichi and Arisu Formations, Kitakami Mountains, Northeast Japan. *Earth Science* (*Chikyu Kagaku*), vol. 39, p. 459-462. (*in Japanese*)

Tazawa, J., 1989: Brachiopoda. *In*, Ofunato City Museum, *ed.*, *Fossils of Onimaru*, p. 51-64, pl. 1, Kawashima Insatsu, Ichinoseki. (*in Japanese*)

Turnau, E., 1978: Spore zonation of uppermost Devonian and Lower Carboniferous deposits of Western Pomerania (N. Poland). *Mededelingen Rijks Geologische Dienst*, vol. 30, p. 1-35, pls. 1-5.

Turnau, E., 1979: Correlations of Upper Devonian and Carboniferous deposits of Western Pomerania, based on miospores study. *Rocznik Polskiego Towarzustwa Geologicnego*, vol. 49, p. 231-269. (*in Polish*)

Utting, J., 1980: Palynology of the Windsor Group (Mississippian) in a borehole at Stewiacke, Shubenacadie Basin, Nova Scotia. *Canadian Journal of Earth Sciences*, vol. 17, p. 1031-1045, pls. 1-3.

Utting, J., 1987a: Palynology of the Lower Carboniferous Windsor Group and Windsor-Canso boundary beds of Nova Scotia, and their equivalents in Quebec, New Brunswick and Newfoundland. *Geological Survey of Canada, Bulletin*, vol. 374, p. 1-93, pls. 1-5.

Utting, J., 1987b: Palynostratigraphic investigation of the Albert Formation (Lower Carboniferous) of New Brunswick, Canada. *Palynology*, vol. 11, p. 73-96, pls. 1-3.

Utting, J., 1991: Lower Carboniferous miospore assemblages from the Hart River Formation, northern Yukon Territory. *Geological Survey of Canada, Bulletin,* vol. 412, p. 81-99, pls. 1-2.

Utting, J., Keppie, J. D. and Giles, P. S., 1989: Palynology and stratigraphy of the Lower Carboniferous Horton Group, Nova Scotia. *Geological Survey of Canada, Bulletin*, vol. 396, p. 117-144, pls. 1-4.

Van der Zwan, C. J., 1980: Aspects of Late Devonian and Early Carboniferous palynology of Southern Ireland. 111. Palynology of Devonian-Carboniferous transition sequences with special reference to the Bantry Bay area, Co. Cork. *Review of Palaeobotany and Palynology*, vol. 30, p. 133-155.

Van der Zwan, C. J., 1981: Palynology, phytogeography and climate of the Lower Carboniferous. *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 33, p. 279-310.

Van der Zwan, C. J. and Van Veen, P. M., 1978: The Devonian-Carboniferous transition sequence in Southern Ireland: Integration of palaeogeography ang palynology. *Palinologia*, vol. 1, p. 469-479.

Van der Zwan, C. J. and Walton, H. S., 1981: The *Cyrtospora cristifer* morphon: Inclusion of *Cornispora varicornata* and *C. monocornata*. *Review of Palaeobotany and Palynology,* vol. 33, p. 139-152, pls. 1-2.

Wood, G. D., Gabriel, A. M. and Lawson, J. C., 1996: Chapter 3. Palynological techniques-processing and microscopy. *In*, Jasonius, J. and McGregor, D. C. *eds.*, *Palynology: Principles and Application*. *American Association of Stratigraphic Palynologists Foundation*, vol. 1, p. 29-50.

Wu, X. Y., 1995: Chapter 3. Carboniferous floras. *In*, Li Xingxue *ed.*, *Fossil Floras of China through the Geological Ages*, p. 78-126. Guangdong Sciences and Technology Press, Guangzhou.

Yang, W. P., 1993: A palynological investigation into Upper Palaeozoic rocks in the suture zone area (W. Yunnan, China) between Gondwana and Laurasia plates and its geological siginificance, unpublished Ph.D. thesis, a joint study between Sheffield University and China University of Geosciences.

Yang, W. P., 1999: Stratigraphic and phytogeographic palynology of late Paleozoic sediments in western Yunnan, China. *Science Reports of Niigata University, Series E*, no. 4, p. 15-99.

Yang, W. P., Neves, R. and Liu, B. P., 1997: Lower

Carboniferous miospores assemblages from the Longba Formation in Gengma, West Yunnan, China and their phytogeographic significance. *Palaeoworld*, no. 7, p. 1–17, pls. 1–2.
Yang, W. P. and Tazawa, J., 2000: Spores and pollen from the Kanokura Formation (Middle Permian) in Kamiyasse, southern Kitakami Mountains, northeast Japan. *Science Reports of Niigata University, Series E*, no. 15, p. 35–47, pl. 1.